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Measuring the angle γ from penguin decays at LHCb

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In this paper we preset first LHCb results on charmless charged two- and three-body B meson decays. In particular, using the first pb^{-1} of integrated luminosity, LHCb observed the $B^0 \to K^+\pi^-$ and $B^+ \to K^+\pi^+\pi^-$ decays. Such decays provide an interesing way to determine the angle γ of the Unitary Triangle, thanks to the possible presence of New Physics in the penguin loops.

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1 Introduction

The family of charmless $B \to h^+h'^-$, where B can be either a B^0 or B_s^0 meson, while h and h' stand for, K or π, are sensitive probes of the Cabibbo-Kobayashi-Maskawa (CKM) [1, 2] matrix and have the potential to reveal the presence of New Physics (NP) as they can occur via tree and penguin amplitudes. One promising way to exploit the presence of penguins for these decays was first suggested ten years ago in Ref. [3] (for the latest update of the analysis see Ref. [4]). In particular, it was shown how the combined measurement of the $B^0 \to \pi^+\pi^-$ and $B_s^0 \to K^+K^-$ time-dependent CP asymmetries, under the assumption of invariance of the strong interaction dynamics under the exchange of the $d \leftrightarrow s$ quarks (U-spin symmetry) in the decay graphs of these modes, provides an interesting way to determine the angle γ of the Unitarity Triangle (UT), without the need of any dynamical assumption. Due to the possible presence of NP in the penguin loops, a measurement of γ with these decays could differ appreciably from the one determined by using other B decays governed by pure tree amplitudes, e.g. $B \to DK$.

For what concerns the charmless charged three-body B meson decays, Ref. [5] depicts a method to extract γ by means of Dalitz amplitude analyses of $B^\pm \to K^\pm\pi^+\pi^-$and untagged B^0 and $\overline{B}^0 \to K_s\,\pi^+\pi^-$. The method is based on the ability to measure independently the relative amplitudes and phases for B^0 and $\overline{B}^0$ decays in a joint untagged sample. The following section will report the first experiences of reconstructing these decays with the first pb^{-1} of integrated luminosity collected by LHCb.

LHCb [7] is a dedicated B physics experiment which exploits the unprecedented quantity of b hadrons produced at the LHC to over-constrain the CKM matrix and search for New Physics (NP) in the flavour sector. The $b\bar{b}$ cross section at the center of mass energy of 7 TeV was first measured by LHCb as $\sigma_{b\bar{b}} = (75.3 \pm 5.4\,(stat.) \pm 13.0\,(syst.))$ mb in the pseudorapidity interval $2 < \eta < 6$ [11].

2 Charmless charged two and three-body B meson decays

2.1 The trigger

The LHCb trigger is a two level system consisting of Level 0 (L0) and High Level Trigger (HLT). The L0 is implemented in hardware, it is designed to reduce the visible interaction rate to a maximum of 1 MHz, at which the whole detector can be readout.

The High Level Trigger (HLT) is the second (and last) level of trigger of LHCb, running on events passing the L0 trigger. It consists of a C++ application that runs on every CPU of the Event Filter Farm (EFF), which will be made out of 1000 16-core

computing nodes when it will fully operate in 2011. The HLT application has access to all data in one event.

The charmless charged two- and three-body B decays are triggered by the L0 requiring at least one cluster in the hadronic calorimeter with a transverse energy higher then a threshold that depends on the rate of the proton-proton interaction. Then the HLT, using a fast track reconstruction, applies a cut on transverse momentum and impact parameter with respect to the primary vertex on the track associated to the triggered L0 cluster.

2.2 The offline selection

The charmless charged two- and three-body B meson decays, due to their branching ratios in the range of $10^{-5} - 10^{-6}$, are selected by applying a set of offline selection cuts necessary to reduce the huge amount of combinatorial background. Inclusive selection strategies are used for both the two and three body decays studies. These are based on a two or three charged tracks selection without particle identification, assigning all tracks the pion mass hypothesis. The discriminating variables include transverse momentum and impact parameters of the daughter tracks, with in addition the common vertex χ^2 and the distance of flight of the B meson candidate. The final analysis makes use of the excellent particle identification provided by the LHCb RICH system. The clear separation between pions, kaons and protons allows very clean invariant mass signals to be obtained for each decay.

2.3 $B \to h^+ h'^-$ decays: results and prospects

Amongst the various modes, the decay with the highest branching ratio, i.e. the $B^0 \to K^+\pi^-$ ($\mathcal{BR}(B^0 \to K^+\pi^-) = (19.4 \pm 0.6) \times 10^{-5}$ [8]), has been clearly observed.

The invariant mass peak of the $B^0 \to K^+\pi^-$ obtained by analyzing 0.9 pb^{-1} of integrated luminosity is shown in Figure 1 (left). The number of signal events is $N_{B^0 \to K^+\pi^-} = 56 \pm 10$, while the direct CP asymmetry, defined as $A^{CP}_{K\pi} = \frac{N_{\pi^+K^-} - N_{\pi^-K^+}}{N_{\pi^+K^-} + N_{\pi^-K^+}}$, is found to be $A^{CP}_{K\pi} = 0.01 \pm 0.16$, where only the statistical error is quoted. This is consistent with the world average ($A^{CP}_{K\pi} = -0.098 \pm 0.012$ [9]).

Detailed studies about the prospects for measuring CP violation, relative branching ratios and the γ angle from $B \to h^+ h'^-$ at LHCb can be found in the LHCb Roadmap document [10]. At that time a $b\bar{b}$ cross section $\sigma_{b\bar{b}} \sim 500\ \mu$b at 14 TeV was assumed. Even with the reduced $b\bar{b}$ cross section measured at 7 TeV, LHCb will be able to perform competitive measurements already using a few tens of pb^{-1} of integrated luminosity, in particular to measure the direct CP asymmetry, the relative branching ratio of the $B^0_s \to K^-\pi^+$ decay and the $B^0_s \to K^+K^-$ lifetime. In order to overcome the current world statistics and measure time dependent CP asymmetries, it will be necessary to accumulate about 500 pb^{-1} of integrated luminosity.

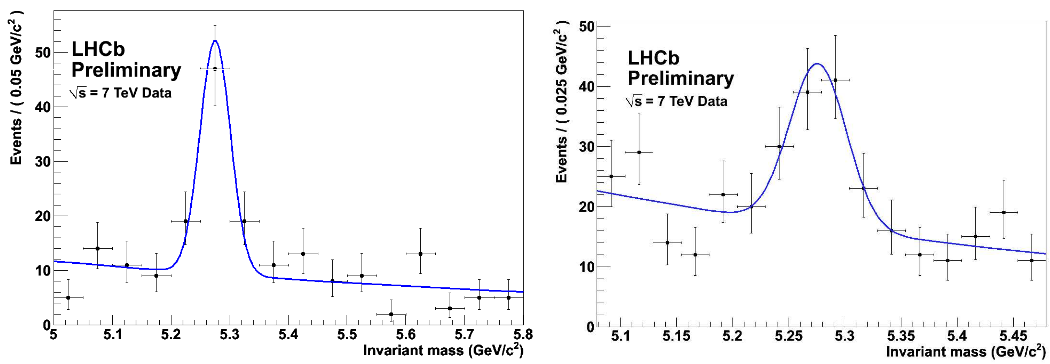

Figure 1: $B^0 \to K^+\pi^-$ invariant mass peak obtained by analyzing 0.9 pb^{-1} of integrated luminosity (left). $B^+ \to K^+\pi^+\pi^-$ invariant mass peak obtained by analyzing 0.55 pb^{-1} of integrated luminosity (right).

For what concerns the angle γ measurement, according to the Monte Carlo studies based on proton-proton collisions at 14 TeV, it is expected to have a sensitivity on γ of about 7° with an integrated luminosity of 2 fb^{-1}.

2.4 $B \to hhh$: results and prospects

The observation of the decay $B^+ \to K^+\pi^+\pi^-$, ($\mathcal{BR}(B^+ \to K^+\pi^+\pi^-) = (5.1 \pm 0.29) \times 10^{-5}$ [8]), has been established by analyzing a sample of 0.55 pb^{-1} of integrated luminosity. The invariant mass peak is shown in Figure 1 (right). The yield is 69 ± 14. Extrapolating this result to an integrated luminosity of 1 fb^{-1}, LHCb will be able to collect about 100k $B^+ \to K^+\pi^+\pi^-$, 30k $B^+ \to \pi^+\pi^+\pi^-$, 10k $B^+ \to K^+K^-\pi^-$, 60k $B^+ \to K^+K^+K^-$, 3k $B^+ \to pp\pi^-$ and 10k $B^+ \to ppK^-$, assuming that all the modes have the same reconstruction and trigger efficiency. LHCb will so surpass the current world statistics by one order of magnitude.

The resonance structures present in three body charmless B^+ decays can be a rich field for CP studies. A model independent approach will be employed to search for statistically significant Dalitz differences between the charged conjugate three body decays. The method is suggested in the Ref. [12].

With the large statistics samples we expect at LHCb in 2011, it will be possible to subdivide the Dalitz plot into different regions to identify what resonance or resonances are the origin of the CP violation. For the decays which have branching fractions bigger than 10^{-5} ($B^+ \to K^+\pi^+\pi^-$, $B^+ \to \pi^+\pi^+\pi^-$ and $B^+ \to K^+K^+K^-$) it is expected to study possible sources of CP violation, while for the other decays the sensitivity will be lower.

3 Conclusions

The analysis of the first pb^{-1} of integrated luminosity collected by LHCb shows very encouraging results for the charmless charged two- and three-body B meson decays. We have already observed the $B^0 \to K^+\pi^-$ ($N_{B^0\to K^+\pi^-} = 56 \pm 10$) and $B^+ \to K^+\pi^+\pi^-$ ($N_{B\to K^+\pi^+\pi^-} = 69 \pm 14$) decays, with yields in agreement with expectations. Assuming an integrated luminosity of over 0.5 fb^{-1}, LHCb will be competitive with and even overcome current world statistics at some point in 2011.

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